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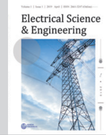

ARTICLE

Validation of Heat Transfer between Theoretical and Experimental from the Internal Surface of Vertical Tubes with Internal Rings Heated by Electrical Heating Coils

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ABSTRACT

The comparison between experimental and theoretical heat transfer inside heated vertical channels that dissipate heat from the internal surface with and without internal rings is studied. The experimental setup consists of a circular pipe which is heated electrically by providing constant heat flux on the wall. The theoretical and experimental analysis is conducted in several pipes of same diameter but different lengths. The length of the pipe varies from 450 mm to 850 mm. The length to diameter ratios are taken as L/D = 10, 12.22, 15.56, and 18.89. The value of imposed heat flux varies from 250 to 3340 W/m2. The internal ring thickness varies from 4 mm to 8 mm. separation distance between the internal rings varies from 75mm to 300 mm. The theoretical results are compared with experimental data to ascertain numerical accuracy of the method. The effects of L/D ratio, thickness of internal rings and separation distance on the heat transfer performance are studied. The experimental result is compared with theoretical, theoretical results are found by using ANSYS. In this study theoretical result for wall temperature along the height of tube, fluid temperature at exit of tube are compared with experimental data.

1. Introduction

Natural convection heat transfer is an exclusive and cost-effective cooling method adopted by electronic industry in order to cool the high voltage electric devices as well as dissipate the heat from the electronic devices or modules which are embedded on a small base. Heat transfer denotes to the transfer of energy taking place in temperature between them. This energy transfer is known as heat. It is known that heat transfer takes place in three modes i.e. conduction, convection and radiation.

It is a known fact that a hot plate of metal cools faster when placed in front of a fan than in front of still air. Thus it can be said that that heat is convected away from the source and this process is called convection heat transfer. It occurs by means of two processes either by forced convection or by natural convection. Forced

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convection is said to occur when the process occurs in presence of external means such as fan or turbine. Natural convection is said to occur when the process of heat transfer takes place due to the variation of density which results from the temperature differences within the surfaces. The density of air is less near the hot surface than that of cooler end and the gravity creates a buoyant force which facilitates the heated air upward. Natural convection has gained a lot of prominence due to its numerous advantages. Currently flow of gaseous heat carriers in vertical plates with natural convection has attracted a lot of attention. Some of the examples of natural convection are nuclear reactors with passive cooling systems, heat loss from steam pipe lines in power plants, cooling towers , domestic convectors , thermo siphons etc.

The purpose of this work is to study theoretically the natural convection on heated vertical tubes and compare with experimental. The test section is a vertical, The test section is electrically heated imposing the circumferentially and axially constant wall heat flux. As a result of the heat transfer to air from the heated surface of the tubes , the temperature of the air increases. The resulting density non-uniformity causes the air in the pipe to rise. The theoretical and experimental analysis is conducted in several pipes of same diameter but different lengths. The length of the pipe varies from 450 mm to 850 mm. The length to diameter ratios are taken as L/D = 10, 12.22, 15.56, and 18.89. The value of imposed heat flux varies from 250 to 3340 W/m2. The internal ring thickness varies from 4 mm to 8 mm. Roul and Nayak [1] studied experimentally heat transfer from internal surface of a tubewhere effects of channel length, ring thickness and ring spacing are observe in detail.Huang et al. [2] studied experimentally the performance of perforate fins and found that with increase in perforation length the heat transfer coefficients increases. Zhang et al. [3] studied heat transfer in cylinders with internal slots and found that Rayleigh number has strong influence on temperature field. Li and Byon [4] studied heat transfer by natural convection around a radial enclosure with rings and developed correlation which could predict the Nusselt numberwithin ±4% error.

Jha and Ajibade [5] observed viscous fluid flow in a sectionbetween two vertical parallel plates taking into account the effect of viscous dissipation. Nayak et.al [6] investigatedheat transfer by natural convection in vertical tubesexperimentally by providingdiscrete rings, and developedcorrelation for Nusselt number and Rayleigh number.Sahoo et al. [7] theoretically analysed the heat transfer phenomena from heated vertical plate having fins and reported that the non-conductive pin fins have an added advantage over the conductive pin fins. The advantage is their low weight which makes it possible to fix the pin fins through glue to any heat transfer surface where augmentation is required. Sahoo et al. [8] also analysed the heat transfer from square conductive and non-conductive fins with inclination of fins. They observed that the rate of heat transfer rises with increase in temperature and fin spacing but reduces with rise in length of the square fin.

Roul and Dash [9] investigated pressure drop in pipe flows and considered the effectiveness of various turbulent models. Tsuji [10] concluded that the improvement of heat transfer from the turbulent natural convection boundary layer can be achieved substantially over a wide area of the boundary layer of natural turbulent convection using heat transfer promoters divided into multiple columns. It can be expected that the improvement of heat transfer in excess of about 40% can be achieved by inserting said promoters. Nayak et.al [11] presented heat transferin vertical tubes experimentally and observed the effect of internal rings inside tube and found that enhancement of heat transfer takes place due to provision of internal rings.Henry k B. and Mikielewicz J. [12] studied a new method for cooling of computers by the implementation of thermo syphon loop with mini channels and mini pump . The results obtained from the model of a one-dimensional two phase thermo syphon loop . It is concluded that at steady state condition the mass flux decreases with the increase in heat flux for friction dominant region. Moreover a co relation was found between the heat transfer coefficient and heat flux for flow boiling in evaporator as well as for flow condensation in cooler. It was found that in both the cases heat transfer coefficient increases with increase in heat flux hence possessing a linear relation between them.

Golachowska et.al. [13] investigated the combustion characteristics of wooden biomass burnt in air and o2 / co2 mixtures in a circulating fluidized bed combustor. The results obtained from the experimental set up were supported by TGA and DTA . These analysis helped to study the thermal behaviour of the mixture. CFB tests observed that the presence of oxidising atmosphere affects the combustion of the biomass fields. Moreover it was observed that there is a 30% and 40% oxygen flow faster in o2 /co2 combustion process . From the DTA graph both exothermic and endothermic reactions were observed. If nitrogen was replaced by carbon dioxide there was delay in the combustion process. Moreover if the amount of oxygen increased beyond 30% the ignition temperature reduced by 10 ◦C and the burnout temperature reduced by 77 ◦C (lower) .

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Porzuczek J.[14].demonstrated a new method by using a fluidized bed boiler for online diagnostics and tuning of temperature controller. Decrease in the bed temperature control quality facilitates activation of the tuning of the controller.It was found that implementing adaptive algorithms and PID controller enhanced the quality of the temperature controller. Here EWMA and EWDEV indicators were used and matlab optimization tool box was used to study the control quality.

Hanuszkiewicz-Drapała M. and Bury T.[15] Studied the use and thermodynamic analysis of horizontal ground heat exchanger to study the heating and cooling system of a residential building by the use of a vapour compression pump. The purpose to provide solution for cooling the buildings in the summer. Parameters whose effects were taken into consideration were heating system, heated building & sub-system. The results were obtained for the analysis of cumulative energy consumption of both the heating and cooling system and cumulative emissions of harmful materials. The results were determined on the effect of utilisation of cooling system for functioning of residential building as well as the effect of influence on thermal state of ground.

Kotowicz J. And Berdowska S.[16] Studied a 600 MW oxy-type cool unit integrated with membrane cryogenic oxygen separation and analysed the influence of parameters such as selectivity co-efficient as well as economic characteristics. The results showed due to increase of membrane O2/N2 selectively also increased which in turn increased the efficiency of power plant. It was found that in the minimal coal unit used with hybrid oxygen plant showed selectivity factor of 30. Kotowicz J. Marcin J.[17] Studied the structural details of damaged zero emission power plant(AZEP). The parameters and thermodynamic analysis of AZEP were also obtained. The paper emphasized the use of Gas turbine with membrane reactor in the place of combustion chamber. It was obtained by use of membrane facilities zero combustion. Here gas obtained was free of nitrogen. The electric efficiency obtained was more than 50%. Hanuszkiewicz-Drapała M. , Bury T. ,And Widziewicz K. [18] studied a cross flow tube and fin heat exchanger. It was followed by computational and experimental analysis of radiative heat transfer impact. The model was designed using computation fluid dynamic software (CFD) ANSYS- fluent design. A numerical model along with computational study showed showed radiative heat transfer increased due to increase in radiation and improved the experimental and numerical results .

Drożyński Z. [19] Studied a new proposal regarding the analysis of steam condensation from a mixture of NCGs. The calculations were based on Berman model along with which equations and assumptions were taken into account. Presence of air in thermal layer was concluded from the analysis which distributed the condensation activity that reduced the efficiency of the process. There is a further scope of improvement of NCG flow. It was further observed from the results that entropy increased due to heat flowing through different thermal layers and hence gradation of the irreversibility problem was solved to a great extent. The results obtained were 21.393 kw/k (water), 17.176 kw/k (steam gas), 10.491 kw/k (condenser) and 2.606 kw/k (fouled surfaces).

Archana et.al.[20] studied the influence of variable thermal conductivity on the stretched flow of Jaffrey nano fluid. The results obtained were with reference to velocity profile, Deborah number, momentum boundary layer etc., Velocity profile was found to increase with increase in Deborah number. It decreased with increase in magneto hydrodynamics. The study showed contrasting behaviour of the velocity profile for the boundary layer thickness, stretching rate parameter. The thermal boundary layer was found to get thicker for different parameters such as radiation, temperature ratio, thermal conductivity, Brownian motion. The Paper exclusively dealt with effects on temperature profile, concentration of boundary layer, Nusselt number. Finally it was concluded that increase of variable thermal conductivity along with radiation , Brownian motion increased rate of heat transfer.

2. Experimental Procedure and Results

Figure1, shows the experimental arrangement, which consists of electrical heating element and equipment for measuring various properties. Pipes of different lengths having45 mm internal diameter and 3.8 mm thickness are considered for this study. Thermocouples are provided tomeasure temperatures on the inside surface at different positions. Electrical heating coils are wound around the circumference of the tube for heating by the supply of electrical energy. Asbestos rope is wound over the heating coil to provide insulation. Other layers of insulation which is applied on the external surface of the pipe are asbestos paste and glass wool as shown in figure 1. Finally, the test section is covered with aluminum foil to reduce radiation heat transfer from exterior surface.

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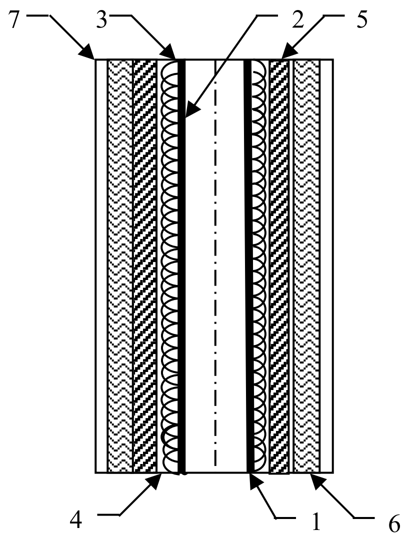
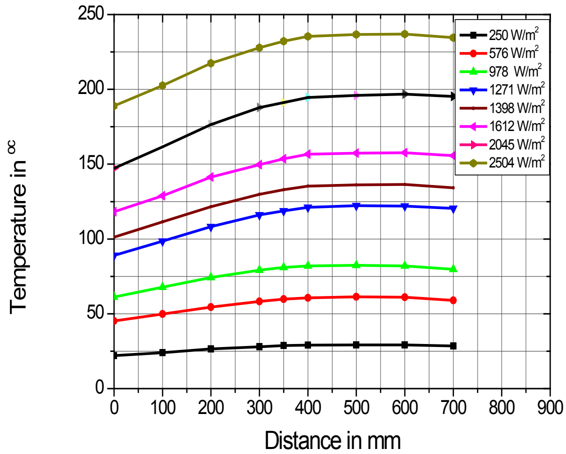


Figure1. Cross section of test pipe

Note: 1. Duct, 2. thermocouples, 3. Electric coil, 4. Asbestos rope, 5. Asbestos paste, 6. Glass wool, 7. Aluminum foil

Experiment is conducted for smooth pipes of various lengths and for various heating levels. Figure 2 shows deviation of wall temperature at different locations for various length to diameter ratio and different heat fluxes. It can be seen from the figure that the wall temperature increases from bottom to the top of the pipe. Figure 3 depicts the air temperatures at the exit of the pipe at different radial distances for smooth tubes for various L/D ratio and for different heating levels. It is evident from the figure that the fluid temperature at the exit of tube decreases from the wall towards the center.



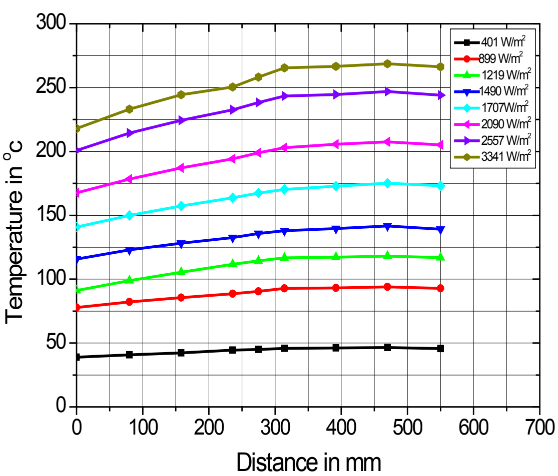


Figure 2. Wall temperature for various heat fluxes for (a) L/D ratio 10 and (b) L/D ratio 18.89

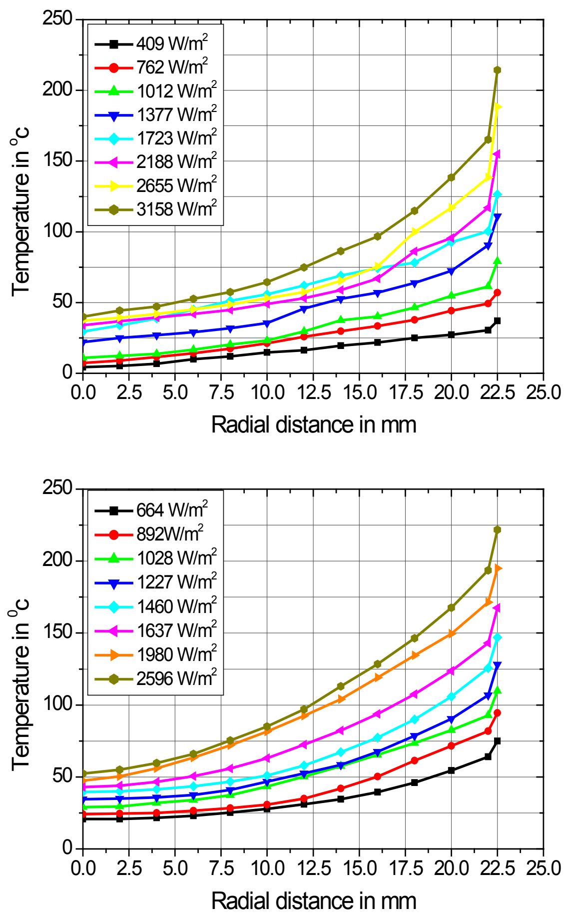


Figure3. Air temperatures at exit of tube at different radial distances for smooth tubes for (a) L/D ratio10 and (b) L/D ratio 18.89

Experiment is also carried out for pipes with internal rings. Figure 4 shows the temperature profile of the air at the exit of the pipe for different wall heat fluxes by pro-

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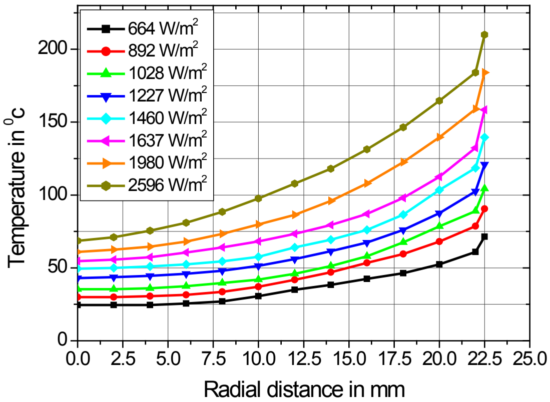
viding protrusions on the internal surface of the pipe. It is evident from the figure that at the center of the pipe the air temperature is minimum and as we move towards the wall the air temperature increases.



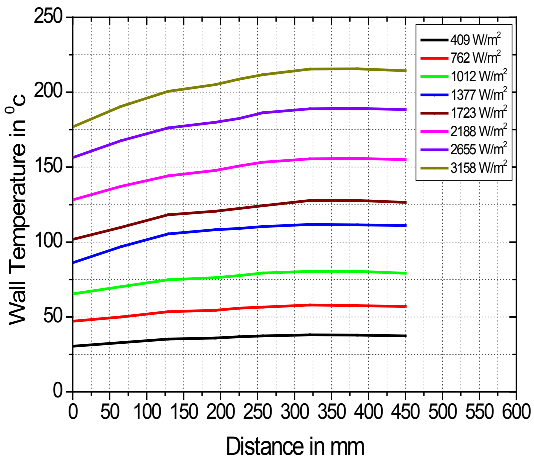


Figure 4. Air temperature at the exit of the smooth pipe with protrusions (L/D = 15.56, t = 4 mm, s = 283.33mm)

3. Theoretical Analysis and Results and Discussion

Natural convection is a result of fluid movement due to changes of density resulting due to heating of air. Buoyancy effect plays a significant role in free convection. The governing equations of continuity, momentum and energy are solved using a finite volume technique to envisage wall temperature and temperature of fluid at exit of the pipe. The resulting wall temperature and fluid temperature are obtained and depicted in figure 5 respectively.Figure 5 illustrates the axial wall temperatures for L/D ratio 10 for different heat fluxes where as figure 5depicts the fluid temperature at exit of tube along radial direction.

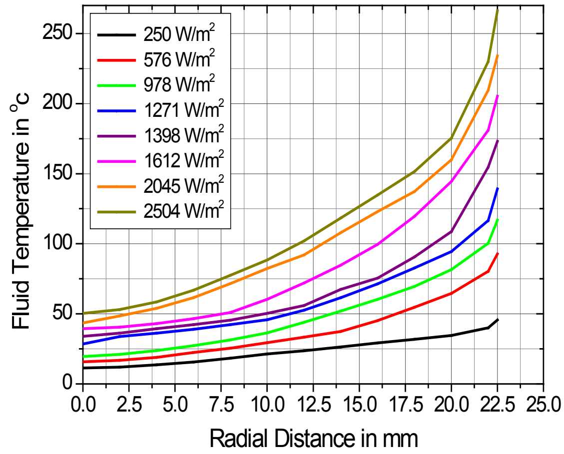


Figure 5. Theoretical result for fluid temperature for L/D= 18.89

Figure 6 shows the comparison of theoretical result for wall temperature with experimental data for L/D=10and 2188 W/m² heat flux. It is evident from the figure that the theoretical result matches very closely with the experimental result. The deviation of theoretical result from the experimental result is found to be less than 5%. Similarly, Figure 7. shows the comparison of theoretical result for air temperature at the exit of pipe with experimental result for L/D=10. It is evident from the figure that the theoretical result matches very closely with the experimental result. The deviation of theoretical result from the experimental result is found to be less than 5%.

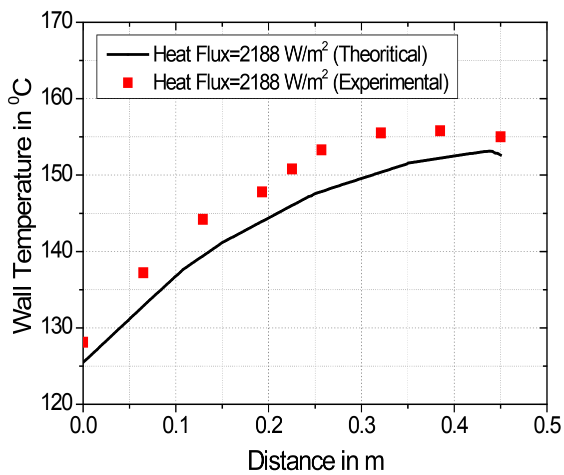


Figure 6. Theoretical result for wall temperature comparison with experimental for L/D=10

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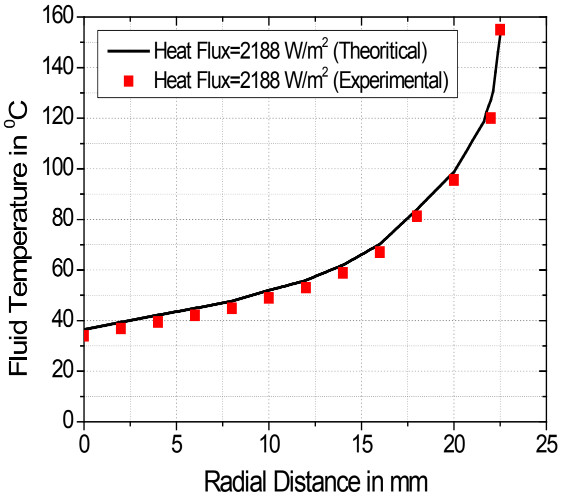

Figure 7. Theoretical result for fluid temperature comparison with experimental for L/D=18.89

4. Conclusions

(1) For constant heat flux conditions, wall temperature increases from bottom to top and air temperature decreases from the wall towards the center of the cylinder. The same trend is observed for both theoretical and experimental results.

(2) Provision of protrusions on the internal surface of a heated vertical cylinder increases the rate of heat transfer from the surface.

(3) As the thickness of the protrusions increases the rate of heat transfer increases up to a certain value of thickness. But further increase in thickness of the protrusions results in decrease in rate of heat transfer.

(4) Rate of heat transfer from the internal surface increases when number of ringsincreases i.e. when spacing between the rings decreases. But further decreasing the spacing beyond a certain value, results in decrease in the rate of heat transfer to the fluid.

(5) The theoretical result for wall temperature is compared with experimental result and it is evident that the theoretical result matches vary closely with the experimental result. The deviation of the theoretical result from the experimental data is found to be less than 5 %.

(6) The theoretical result for fluid temperature measured radially at the exit of pipe is compared with experimental result and it is evident that the theoretical result matches vary closely with the experimental result. The deviation of the theoretical result from the experimental data is found to be less than 5 %.

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